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Air Intakes for Subsonic UCAV Applications - Some Design Considerations

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Outline

- Some first expectations from theory
- Practical considerations
- Research requirements

Mission Assumptions

- Modest manoeuvre requirements
- Subsonic cruise

What's New?

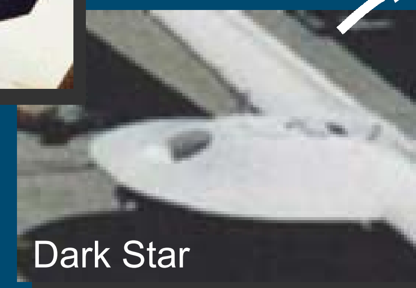
- Some additional positioning and packaging freedoms
  - Upper surface front position is available
- . . . But many new constraints due to a need for low observability
  - No diverter
  - High lip sweep / edge alignment
  - Engine compressor face obscuration
  - Fixed geometry and no auxiliary intakes (ideally)

Intake Configuration Examples

- Pitot

- Diverter-
  less pitot

- Semi-flush



- Flush

Getting easier
to satisfy LO
constraints

. . . but

Increasing
aerodynamic
integration
difficulty

Photos © Jane's

Practical Considerations:

Vehicle Packaging

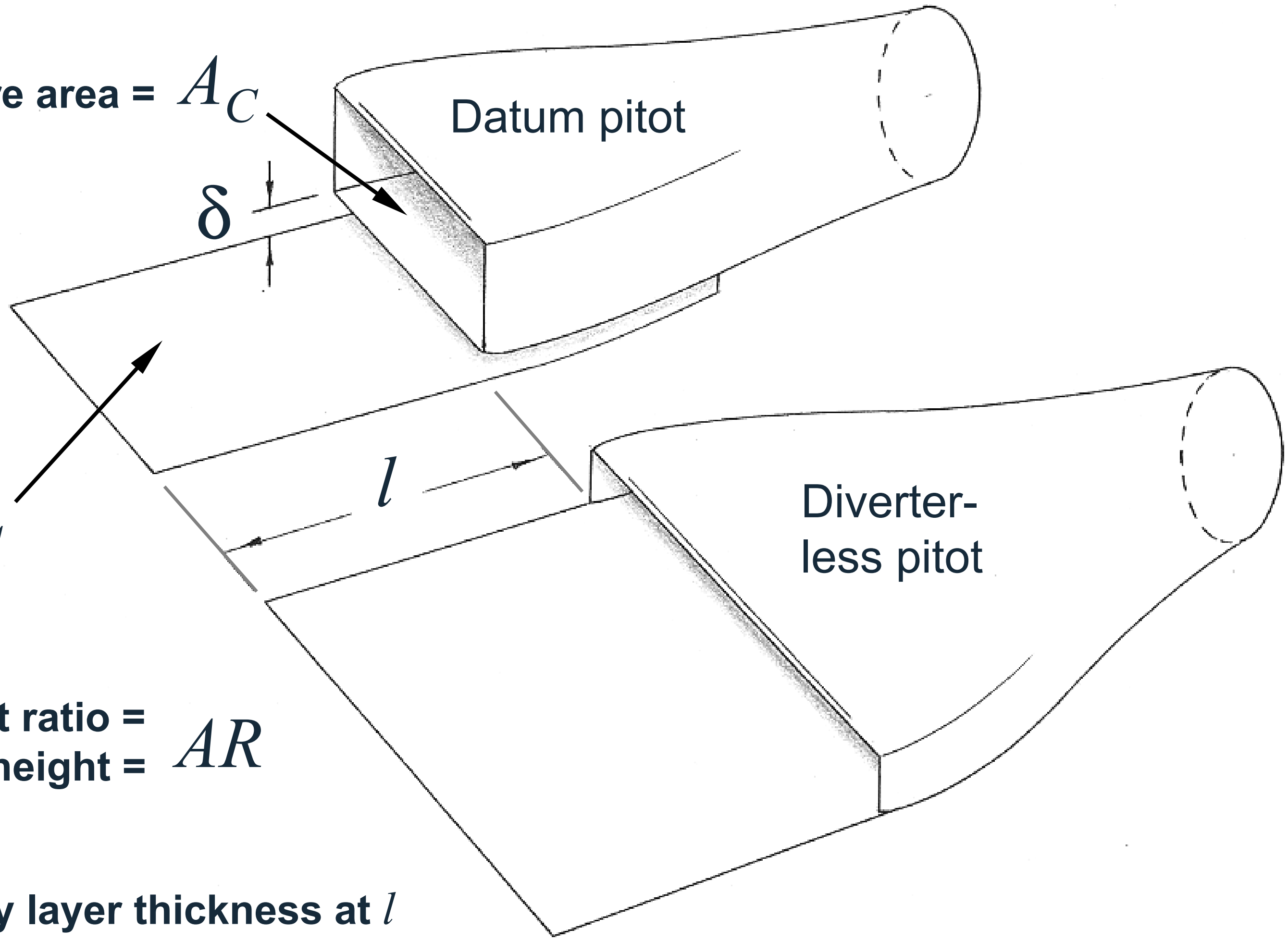
- Tendency for fuel, releasable payload and engine to need to be near to the CG
- Intake options
  - At or near to the front of the vehicle

    . . . but avoiding wing leading-edge vortex ingestion
- Diffuser options:
  - Very short diffusers with compressor-face screening devices
  - Short, highly off-set, obscuring diffusers

Idealised Pitot Intakes

Intake capture area = A_C

Area of approach surface = S

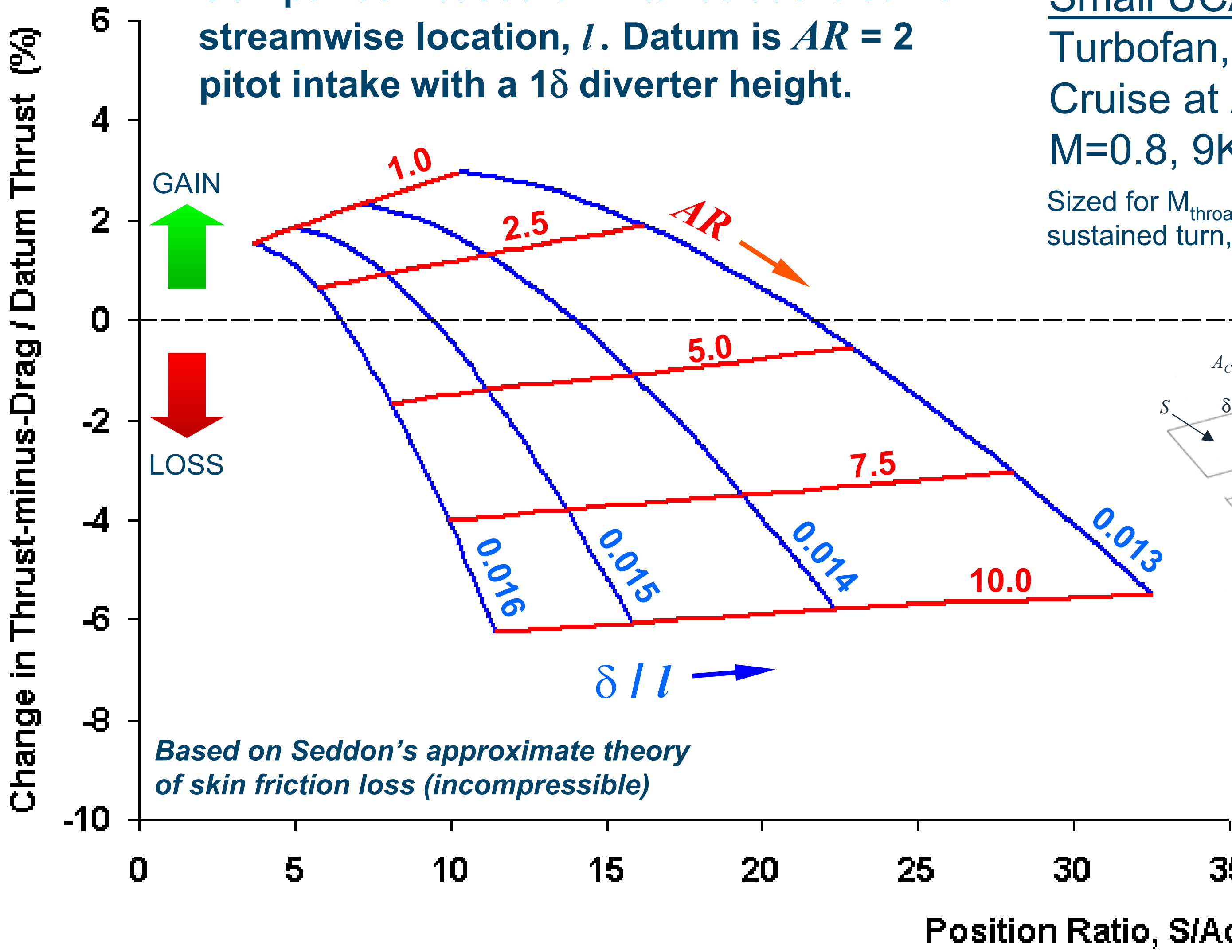


Intake aspect ratio = width / height = AR

δ is boundary layer thickness at l

Divert, Ingest or a Bit of Both?

Comparison based on intakes at the same streamwise location, l. Datum is AR = 2 pitot intake with a 1δ diverter height.



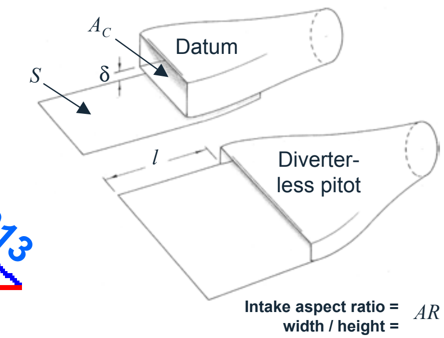
Small UCAV

Turbofan, BPR=0.1

Cruise at A_0/A_C=0.67

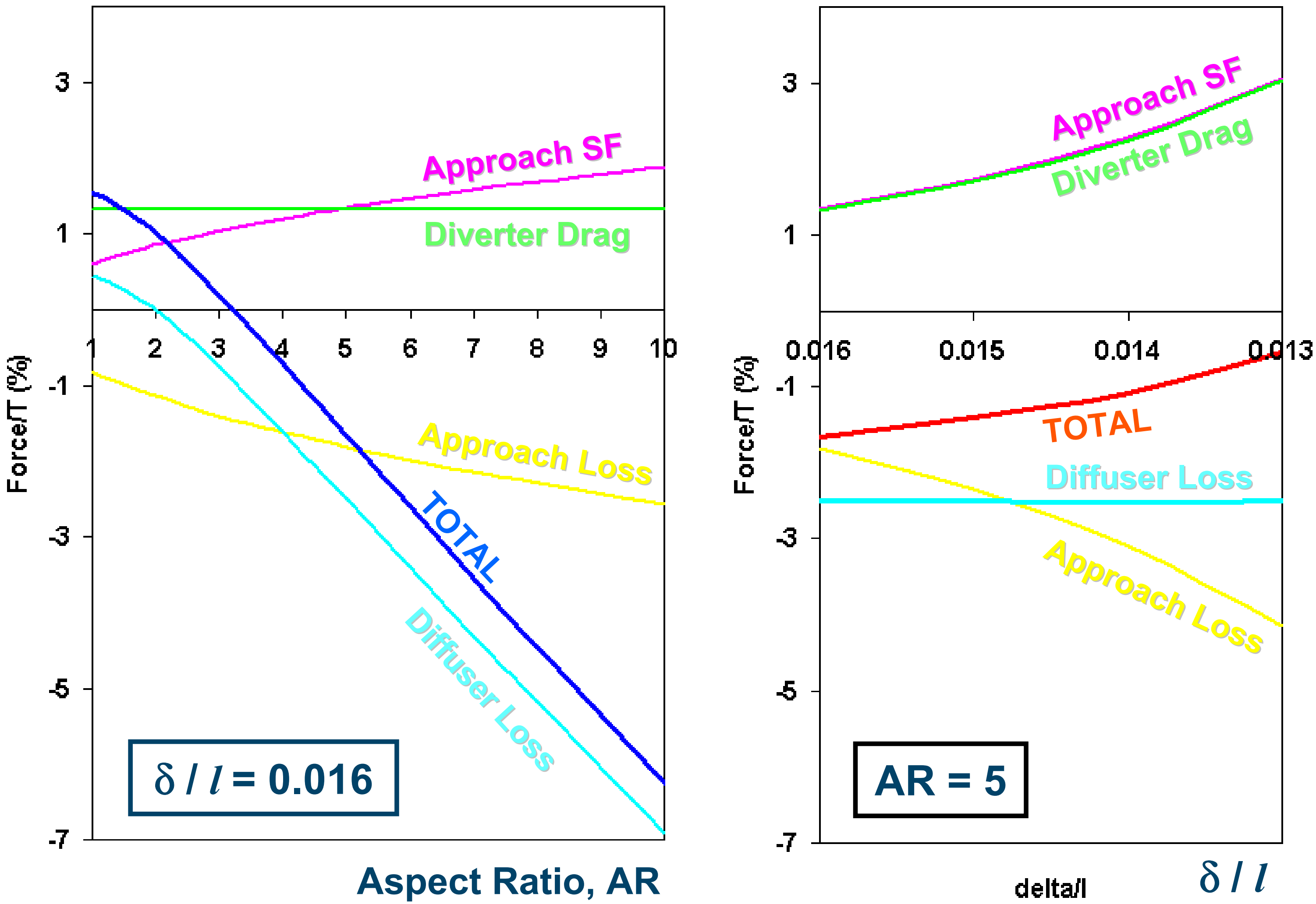
M=0.8, 9Km ISA

Sized for M_{throat}=0.85 in 2g sustained turn, M=0.8, 9Km ISA

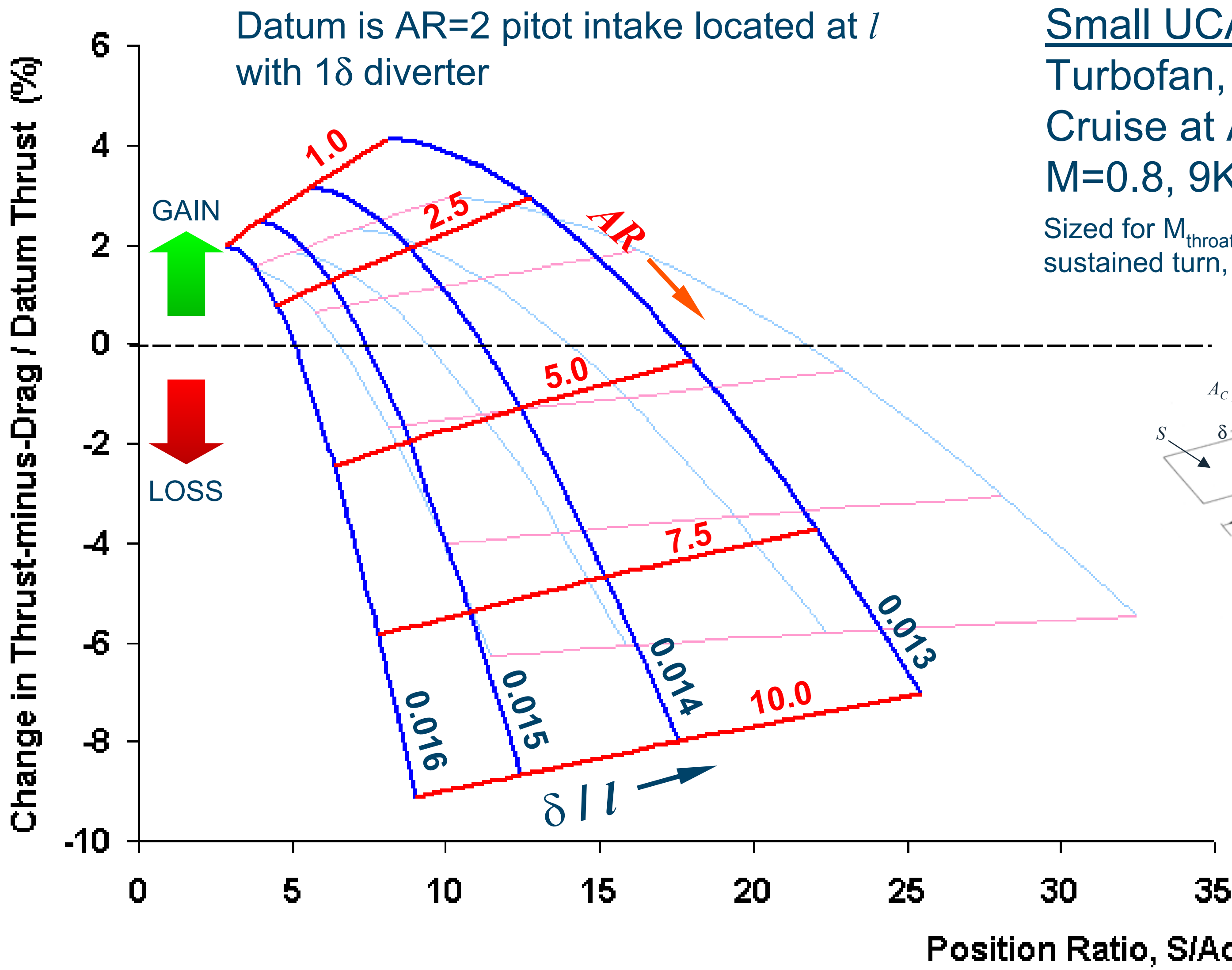


Contributions to Δ(T-D)/T

BPR = 0.1



Divert, Ingest or a Bit of Both?



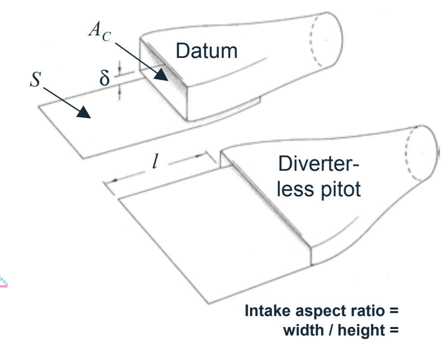
Small UCAV

Turbofan, BPR=1.0

Cruise at A_0/A_C=0.73

M=0.8, 9Km ISA

Sized for M_{throat}=0.85 in 2g sustained turn, M=0.8, 9Km ISA



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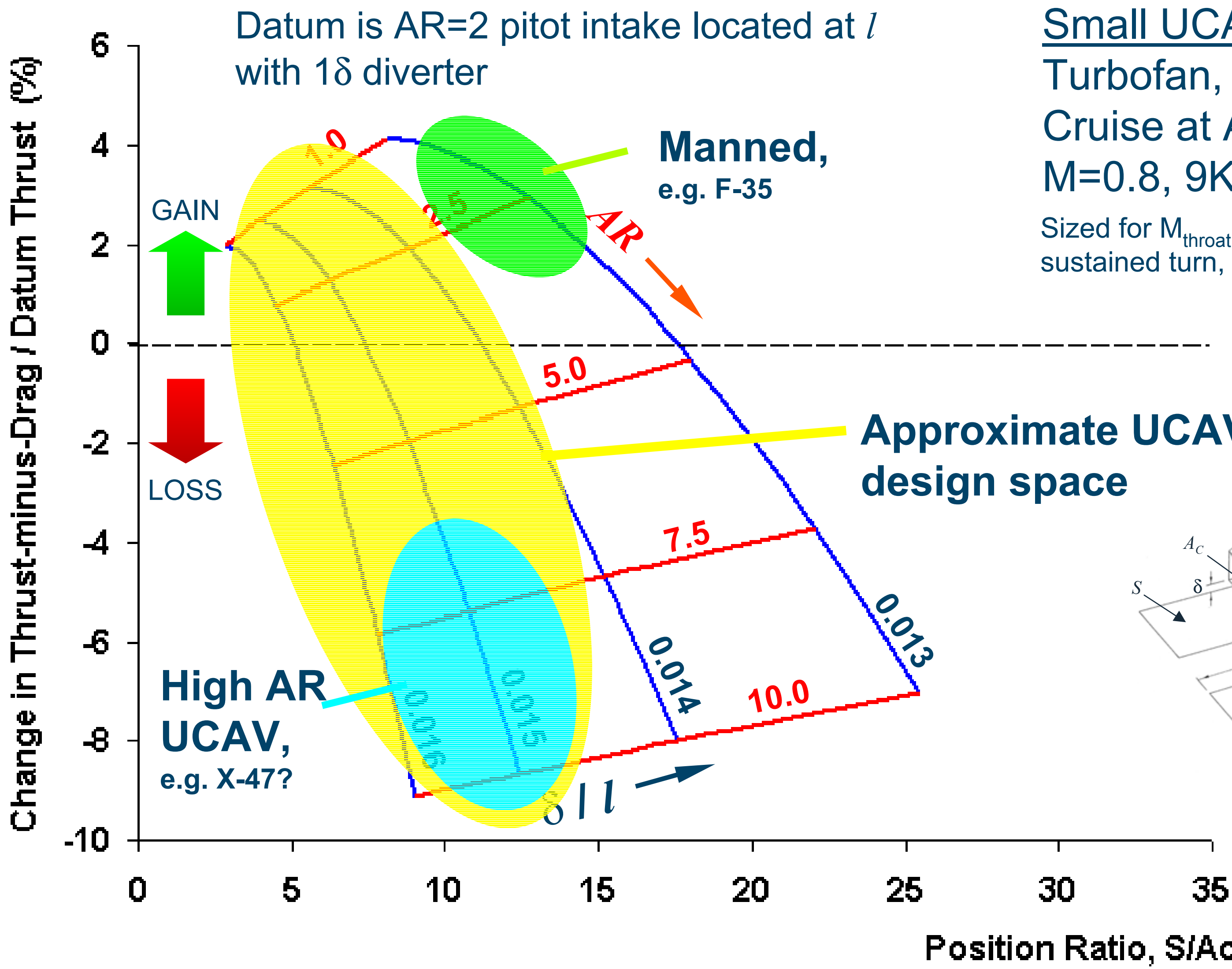

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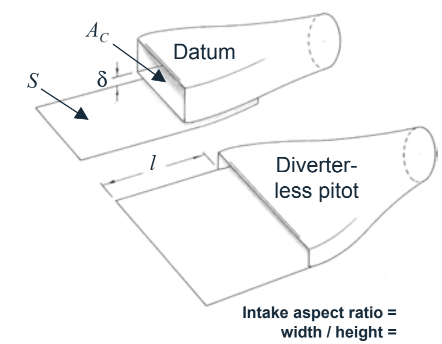


Practical Considerations:

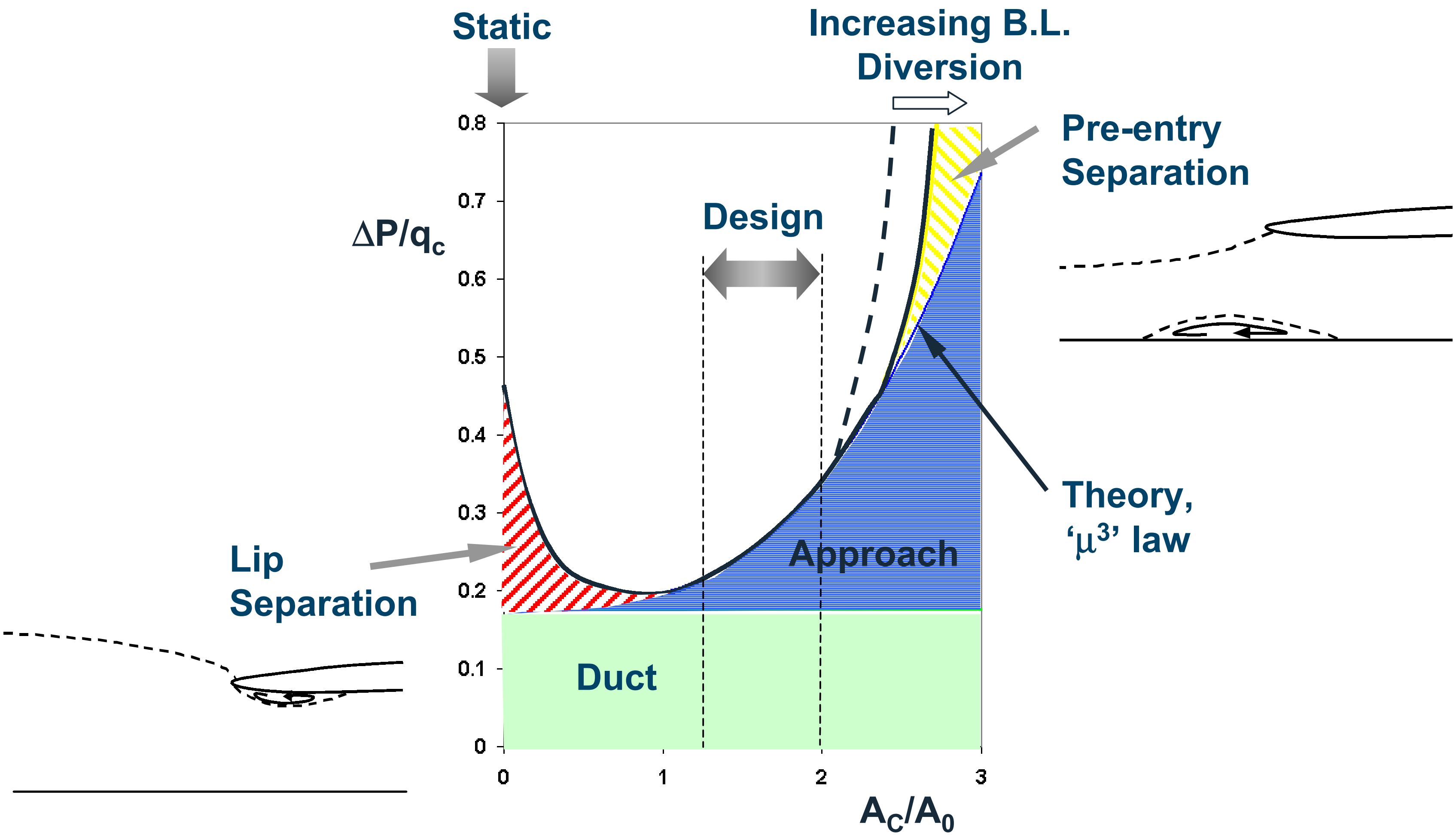
Avoidance of Distortion and Swirl

- Boundary layer ingestion can look like a good idea in principle but:
  - Distorted flow at the diffuser entry can adversely influence the diffuser flow

  . . . leading to additional loss, increased distortion and swirl at the compressor face

- The classical diverter gap is a convenient way of avoiding this problem and is seen on almost all non-LO aircraft that operate above M=0.6

Flow Capture Ratio Effects



Practical Considerations:

Pre-Entry Separation Problem

- Design for operation at higher cruise mass flow ratio than normal will lead to :
  - Lower spillage drag at cruise

. . . but increased losses at all conditions due to:

  - A smaller intake capture area with higher throat Mach number
  - An increased internal diffusion requirement

- Static/take-off or manoeuvre thrust requirement and cruise performance requirement are thus likely to conflict

Research Requirements:

Intake Pre-Entry Flows

- Ways of controlling the pre-entry flow e.g:
  - Boundary layer conditioning via surface shaping (e.g. bumps)
  - Boundary layer diversion via intake shaping (forward swept intakes, NACA intakes)
- Efficient ways of accommodating distorted in-flows

Practical Considerations:

Lip Separation Problem (1)

- Lip planform
  - Highly swept planforms can lead to locally high lip loading which is potentially a problem for high mass flow ratio operation (e.g. static and take-off regimes)
- Contraction ratio
  - High CR desirable for performance and compatibility at static, take-off and manoeuvre conditions
  - But, combining high CR and high cruise mass flow ratio would mean:
    - Even higher throat Mach number
    - Even higher internal diffusion requirement

Practical Considerations:

Lip Separation Problem (2)

- Spillage drag
  - High cruise mass flow ratio, so spill drag issue should tend to be of reduced significance
  - But still potentially an issue in the case of very high lip sweep and/or sharp lips

Research Requirements:

Intake Entry and Lip Shaping

- Ways of improving the static and take-off performance of fixed-geometry intakes
- Aerodynamics of highly compromised intake lip profiles (e.g. sharp / bi-convex of varying thickness)

Practical Considerations:

Diffuser Flows

- Diffuser likely to provide the most significant contribution to thrust loss at cruise
- High diffuser off-set will tend to significantly increase pressure loss, distortion and swirl so great care is required in design
- Benefits likely through tailoring of area distribution, cross sectional shape / local wall curvature
- Flow control systems could offer very significant benefits
  - Suppression of flow separation
  - Re-distribution of low energy flow

Research Requirements:
Diffusers

- Parametric study of compact diffusers with high aspect ratio entries (both with and without obscuration) using a combination of experiment and CFD
- Ways of reducing total pressure distortion and swirl in compact diffusers with minimal additional diffuser loss
  - e.g. flow control systems of various forms
- Novel approaches to diffusion and screening

Research Requirements:

Prediction Methods

- Effective, rapid, methods for the estimation of the contribution of intake components to intake performance (e.g. semi-empirical) for preliminary design
- Methods for the prediction of complex flows (including time-variant flows) in complex intake and diffuser combinations both with and without flow control systems
- Methods for the optimisation of complex intake and diffuser combinations both with and without flow control systems

Conclusions

- Unmanned and LO . . . New freedoms but many new design challenges
- Systematic research on basic intake and duct parameters is required to extend the current knowledge into the full UCAV intake design space
- There is plenty of scope for novel solutions
- A high degree of integration with the airframe is likely to be required

  . . . so rapid estimation methods are needed more than ever at the conceptual design stage
- High-order CFD systems can capture key flow features of interest

  . . . target is cost-effective prediction of absolute performance levels
- Optimisation methods could be of great assistance in the later stages of the design process

Thanks for your attention !